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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE

No. 1464

EFFECTS OF SURFACE FINISH, OF CERTAIN DEFECTS, AND OF REPAIR  
OF DEFECTS BY WELDING ON FATIGUE STRENGTH OF 355-T6  
SAND-CASTINGS AND EFFECTS OF PRIOR FATIGUE  
STRESSING ON TENSILE PROPERTIES

By F. M. Howell, G. W. Stickley, and J. O. Lyst

Aluminum Company of America



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SUMMARY

Tests were made to evaluate the effects of various surface conditions, of certain defects, and of repair of some of these defects by welding on the fatigue strength of an aluminum sand-cast alloy. The surfaces studied included as-cast, machined, grit-blasted, and shot-blasted surfaces. The unsound conditions included different degrees of porosity and other kinds of defect sometimes present in castings which might affect their fatigue strength. Fatigue tests were made of 355-T6 sand-cast plate-type specimens subjected to direct stress from zero to a maximum value in tension, and tensile tests of those specimens that did not fail in fatigue were also made.

The results showed that the compositions and tensile properties of the castings comply in general with the requirements of A.S.T.M. and government specifications. The fatigue strength of the normally sound castings with as-cast surfaces, based on 25,000,000 cycles of stress, was found to be about 70 percent of the fatigue strength determined by using small polished round specimens tested in direct stress. Surface treatments, such as shot-blasting or grit-blasting, increased the fatigue strengths at 25,000,000 cycles about 35 percent. The amount of porosity in the range from 0.8 to 2.4 percent had no effect on fatigue strength of castings tested with the surfaces as-cast. When the surfaces were machined, the castings with the larger amount of porosity had somewhat lower fatigue strength, the difference at 25,000,000 cycles being about 15 percent. Sand holes decreased the fatigue strength and were more harmful when located at the edge than when located near the center of the specimen. The fatigue resistance of castings having defects may be improved or completely restored by welding and reheat treating. The amount of improvement depended upon the size and character of the defects and the quality of the welds. Dross inclusions, when present either in massive form or ribbon-shaped, were more harmful when at the edge of the specimen than when at the center. Ribbon-shaped dross inclusions were harmful when they extended in the transverse direction but had no effect when parallel to the direction of loading.

Intentional defects, represented by aluminum strips inserted on edge in the molds before casting, when oriented transversely lowered the fatigue strength slightly but when oriented longitudinally had little or no harmful effect.

The tensile properties of the specimens previously subjected to fatigue stressing without failure had not been harmed by the fatigue stressing. The tensile strengths and elongations of the plate-type specimens with as-cast surfaces, including not only the sound castings but also those with different degrees of porosity, agreed closely with the properties of the separately cast test bars. The yield strengths of the plate-type specimens generally were slightly higher. Grit-blasting the surfaces of the plate-type specimens had no harmful effect on the tensile properties. Shot-blasting lowered the tensile strength about 9 percent but increased the yield strength slightly. The specimens containing welds had tensile strengths about 4 percent less than the sound specimens without welds.

## INTRODUCTION

The object of this investigation of 355-T6 sand-cast alloy was to determine: (1) its fatigue characteristics under repeated tensile stresses ranging from zero to a maximum value by using specimens of relatively large size and (2) the effects of prior fatigue stressing upon the tensile properties of the alloy. The investigation included tests to determine the effects of various surface finishes, including grit-blasted and shot-blasted surfaces; of various types of defect; and of repairing defects by welding.

## MATERIALS

The specimens used for this investigation were sand-cast plate-type specimens of the general design shown in figure 1. The reduced sections were about  $\frac{1}{4}$  inch thick and, in general,  $7\frac{1}{2}$  inches wide, although a few were only  $5\frac{1}{2}$  inches wide. Most of the specimens were tested with the surfaces of the reduced section as-cast; those that were tested with machined surfaces were cast with a reduced section about  $\frac{1}{2}$  inch thick and machined to a thickness of  $\frac{1}{4}$  inch. The thickness of the reduced sections was from 0.010 to 0.058 inch less at the center than at the ends. Fourteen lots of castings were prepared. A brief description of each lot is given in table I.

The analyses of the different lots were within the specified limits for 355 alloy. These limits, together with the nominal composition, are as follows:

Element	Nominal composition (percent)	Specification limits (A.S.T.M. specification B26-46T, alloy SC2L) (percent)
Copper	1.3	1.00 to 1.50
Iron	---	.6 maximum
Silicon	5.0	4.5 to 5.5
Magnesium	.5	.4 to .6
Manganese	---	.1 maximum
Zinc	---	.1 maximum
Chromium	---	.2 maximum
Titanium	---	.2 maximum

The tensile properties of the various lots, as determined from standard separately cast  $\frac{1}{2}$ -inch-diameter test bars, are given in table II, together with the typical and specification values. The tensile properties in general were satisfactory, although the elongation of lot L-2258 was below the specified minimum value of 2.0 percent. (A.S.T.M. specification B26-46T, alloy SC2L; federal specification QQ-A-601, class 10; Army-Navy aeronautical specification AN-A-40.)

## TEST PROCEDURE

### Fatigue Tests

The fatigue tests were made in the structural fatigue machines shown in figure 2 which were designed primarily for testing large riveted joints (reference 1). The machines are so constructed that the specimens may be subjected to cycles of direct stress from any value in tension or compression to any other value in tension or compression within the limits of their load capacity ( $\pm 40,000$  lb, when used with the adapters shown in fig. 3). The specimens in this investigation, however, were stressed only from zero to a maximum stress in tension. The desired loads are obtained by proper adjustment of the eccentric at the end of the loading beams. These loading beams act as second-class levers alternately applying and releasing the load on the specimen as the beams are actuated up and down by the eccentric. In order to minimize any bending stresses at the ends of the reduced section in the specimen, adapters with plate fulcrums as shown in figure 3 were used.

The end faces of each specimen were machined so that the vertical center line of the reduced section of the specimen (edge view) is  $\frac{1}{2}$  inch from the plane of the end faces. In order to insure uniform loading, the keyways of the specimen were machined parallel within 0.001 inch in 14 inches, the same as the keys in the machine. The specimen was fastened to the testing machine by being bolted and keyed in place in a vertical position as shown in figure 3. The outer edges of each specimen were machined throughout their length in order to provide smooth edges. In addition, the edges throughout the reduced section were rounded slightly to minimize stress concentrations. This rounding was done by rubbing longitudinally with emery cloth. Some of the specimens had the surfaces of the reduced section machined. The shape of the reduced section and the condition of the surfaces of each specimen are indicated in tables III to VI.

Most of the tests were continued to failure but 11 were discontinued before failure because the number of cycles had reached at least 25,000,000, which was considered sufficient in this investigation. Subsequently the specimens from these tests were tested to failure in tension.

#### Tensile Tests

The tensile tests were conducted in a 300,000-pound-capacity Amsler universal testing machine, as shown in figure 4. The adapters, to which the specimens were keyed and bolted, were built so that the axis of loading coincided with the vertical center line of the reduced section of the specimen. The adapters were attached to the heads of the testing machine by means of tension bolts having spherical seats.

Strain measurements sufficient to obtain the yield strength were made on each specimen, except that two specimens failed before an offset of 0.2 percent was reached. The measurements of the 11 specimens previously subjected to fatigue stresses were made on 6-inch gage lengths on opposite edges of the specimens by using dial indicators having one division equal to 0.001 inch. The measurements on the specimen not tested in fatigue (C-1205-H) were made by using an SR-4 strain indicator, with six resistance wire strain gages cemented to the specimen at the center of the gage length. Three gages were placed on each face of the specimen across the center line, with one gage at each edge and the third at the center.

The elongation of each of the 11 specimens previously subjected to fatigue stresses was measured over 2-, 4-, and 6-inch gage lengths on three sets of gage marks placed about  $\frac{3}{8}$  inch from each edge and at the center of the width on one face of each specimen at the reduced section. The gage marks were spaced 1 inch apart along lines parallel to the axis of the specimen. No elongation measurements were made on the specimen not subjected to fatigue stresses (C-1205-H).

## DISCUSSION OF RESULTS

## Fatigue Tests

The results of the individual fatigue tests are given in tables III to VI and are plotted in figures 5(a) to 5(g). Typical examples of the various types of failure are shown in figures 6 to 11.

The individual test data for the specimens with as-cast surfaces and without intentional defects are summarized in table III and are plotted in figure 5(a). The solid curve has been drawn through the points representing specimens from lot L-2246 and is in good agreement with the results of tests of the other two lots, L-2238 and C-175. As a basis for comparison, this curve is also shown in figures 5(b) to 5(g). The fatigue strength at 25,000,000 cycles was 6900 psi. This is about 20 percent of the tensile strength determined from  $\frac{1}{2}$ -inch-diameter test bars from lot L-2246. For comparison, the curve obtained in similar direct-stress fatigue tests of small polished specimens of the same alloy is also shown in figure 5(a). As might be expected, the fatigue curve for the large specimens with as-cast surfaces is considerably below the curve for the polished specimens.

The effects of surface treatments, such as grit-blasting and shot-blasting, are shown in figure 5(b). The curves indicate rather definitely that, at stresses below 10,000 psi, both grit-blasting and shot-blasting improve the fatigue strength considerably. The fatigue strengths of the grit-blasted and shot-blasted specimens each were about 9300 psi at 25,000,000 cycles or an increase of about 35 percent over that of specimens having as-cast surfaces. One test of a sand-blasted specimen was made, and the results of it also are shown in figure 5(b). The results of this test indicate that the effect of sand-blasting is about the same as that of grit- and shot-blasting.

The data for specimens containing two degrees of porosity, about 0.8 and 2.4 percent, respectively, are shown in table V. A porosity of 0.8 percent represents about the maximum commercial quality, and a porosity of 2.4 percent represents the minimum quality. There were two groups of castings with each degree of porosity, one tested with as-cast surfaces and one with machined surfaces. The results of the tests of the specimens with as-cast surfaces are plotted in figure 5(c) and indicate no definite difference in fatigue strength. The results for the specimens with machined surfaces are plotted in figure 5(d) and indicate large differences. Although the specimens with the smaller degree of porosity had about the same fatigue strength as that of specimens with as-cast surfaces and no intentional defects, those with the larger degree of porosity had considerably lower fatigue strength. The machining probably made any notch effect of the pores more harmful, for the metal removed from the surface during machining would be less porous than that at the center.

The results of tests made to study the effects of certain casting defects upon fatigue resistance are shown in figure 5(e). Included also are the results of tests of specimens with defects repaired by welding. In three tests the specimens contained sand holes,  $\frac{1}{4}$  inch in diameter and  $\frac{1}{8}$  inch deep, the sand holes being at the edge in two specimens and at the center of the other one. These three tests indicate that sand holes affect the fatigue strength of the castings and are more harmful when at the edge of the test section than when at the middle. One test was made in which a sand hole at the edge of the specimen had been repaired by welding. The results indicate the fatigue strength to be about the same as that of specimens free from defects. Six tests were made on specimens having a weld about  $1\frac{5}{8}$  inches long and  $\frac{3}{4}$  inch wide at the edge of the test section, and seven tests were made on specimens with a weld about  $1\frac{1}{2}$  inches in diameter at the center of the section. These specimens were heat-treated after welding, and when checked radiographically the welds were found to be sound. Although there was some scatter, the test results indicate that it is possible by welding to restore the fatigue resistance of castings containing defects. This, however, was not accomplished in every case. The improvement resulting from welding would be expected to be dependent upon the size and character of the defect and the quality of the weld. In 9 of the 12 welded specimens that failed, the failures occurred through the weld or at the edge of the weld.

The results of tests of four specimens with several types of dross inclusion are shown in figure 5(f). In two of the specimens the dross was in massive form, and in the other two it was present in the form of a film. In the specimens containing dross in massive form, the dross was at the edge of one specimen and in the center of the other. In the specimens containing dross in the form of a film, the film extended transversely at the center of one specimen and longitudinally at the center of the other. All four tests were made at the same stress, 9000 psi. They indicate that dross inclusions at the edge of a specimen are more harmful than those at the center. Also, dross films in the transverse direction are more harmful than those in the longitudinal direction. The dross inclusion in massive form at the center of the specimen and the ribbon-shaped dross located longitudinally in the center of the reduced section had practically no effect on the endurance properties. The failures in the specimens containing these two types of inclusion did not occur at the defect but at the end of the reduced section. The failures of the other two specimens occurred through the defects.

Five specimens were cast with metal inserts at the center of the reduced section to simulate defects. The inserts consisted of aluminum strips  $\frac{1}{16}$  inch thick,  $\frac{3}{4}$  inch long, and having a width equal to the thickness of the specimen. In one of the specimens the plane of the strip was

in the longitudinal center line normal to the surfaces of the specimen; in the other four specimens, the strips lay in a transverse plane. The effects of these intentional defects are shown in figure 5(g). When the strips extended transversely, the harmful effects appeared greater at higher stresses but were quite small when the fatigue life was more than 1,000,000 cycles. All but one of the specimens with transverse defects failed through the defect. When oriented longitudinally the defect had little or no harmful effect on the fatigue life. The failure did not occur at the intentional defect but at the end of the reduced section.

### Tensile Tests

The results of the tensile tests are summarized in table VII and are shown graphically in figure 12. In this figure, the results of the tests of the separately cast test bars are shown for comparison.

The broken plate-type specimens are shown in the photographs of figures 13 and 14. Nine of the specimens failed at the center of the reduced section; of the three that did not, at least two had casting defects which were responsible for the location of the fractures.

The tensile and yield strengths of the plate-type specimen that had not been tested in fatigue (C-1205-H) were within 3 percent of the values determined for the separately cast test bars. The values agree well with the typical properties for 355-T6 alloy.

The tensile properties of the plate-type specimens with as-cast surfaces and without intentional defects (L-2246-8 and R-9526-7) that had been previously tested in fatigue were about the same as those determined for the specimen that had not been subjected to fatigue stresses. The tensile properties also agree closely with those of the corresponding separately cast test bars. These tests indicate that the fatigue stressing was not detrimental to the static properties of the plate-type specimens.

The two grit-blasted, plate-type specimens (L-2246-4 and L-2246-12) had about the same tensile properties as the plate-type specimens with as-cast surfaces. This indicates that grit-blasting has little if any effect on the tensile properties.

One plate-type specimen with shot-blasted surfaces (L-2257-13) had a tensile strength about 9 percent lower than the corresponding separately cast test bars but it was still well above the minimum specification value for 355-T6 alloy. The yield strength was slightly higher than those of the test bars. The other shot-blasted specimen failed through a defect before sufficient deformation was obtained to determine the yield strength. The properties of this specimen were not included in the averages shown in table VII.

The tensile properties of the specimen with 2.4-percent porosity (R-9524-6) were about 10 percent lower than those determined for the sound specimens. The specimen failed through a defect near one end of the reduced section, which was probably responsible for part of the decrease in properties.

The tensile strength of one of the specimens with 1.65-percent porosity (R-9525-5) was about 5 percent lower, and the elongation about one-third less, than the values for the sound specimens, but there was no difference in yield strength. The other specimen from this lot (R-9525-7) failed through a defect; therefore its properties are not included in the average values in table VII.

The tests of the two specimens, each containing a weld at the center of the reduced section, indicated that the weld lowered the tensile strength about 4 percent but did not affect the yield strength. Each of these specimens failed through the center of the weld.

Comparison of the results obtained from the tests of the plate-type specimens with those obtained from tests of the corresponding separately cast test bars shows that the tensile strengths agree within about 3 percent when the specimens with shot-blasted surfaces and those containing welds or defects are not considered. The yield strengths of the plate-type specimens were generally slightly higher than those of the separately cast test bars, and in one case the difference was as much as 20 percent.

### CONCLUSIONS

The results of the fatigue tests of 355-T6 sand-cast plate-type specimens subjected to direct stress from zero to a maximum value in tension and the subsequent tensile tests of those specimens that did not fail in fatigue justify the following general conclusions:

1. The compositions and tensile properties of the castings complied in general with the requirements of A.S.T.M. and government specifications.
2. The fatigue strength of the normally sound castings with as-cast surfaces was 6900 psi, based on 25,000,000 cycles of stress. This value is about 70 percent of the fatigue strength determined by using small polished round specimens tested in direct stress.
3. Surface treatments, such as shot-blasting or grit-blasting, increased the fatigue strengths at 25,000,000 cycles about 35 percent.
4. The amount of porosity in the range from 0.8 to 2.4 percent had no effect on fatigue strength of castings tested with the surfaces as-cast. When the surfaces were machined, the castings with the larger amount of porosity had somewhat lower fatigue strength, the difference at 25,000,000 cycles being about 15 percent.

5. Sand holes  $\frac{1}{4}$  inch in diameter and  $\frac{1}{8}$  inch deep decreased the fatigue strength and were more harmful when located at the edge than when located near the center of the specimen.

6. The fatigue resistance of castings having defects may be improved or completely restored by welding and reheat treating. The amount of improvement depends on the size and character of the defects and the quality of the welds.

7. Dross inclusions, when present either in massive form or ribbon-shaped, may have a harmful effect upon fatigue strength. They were more harmful when at the edge of the specimen than when at the center. Ribbon-shaped dross inclusions were harmful when they extended in the transverse direction but had no effect when parallel to the direction of loading.

8. Intentional defects, represented by aluminum strips inserted on edge in the molds before casting, when oriented transversely lowered the fatigue strength slightly but when oriented longitudinally had little or no harmful effect.

9. The tensile properties of the specimens previously subjected to fatigue stressing without failure had not been harmed by the fatigue stressing.

10. The tensile strengths and elongations of the plate-type specimens with as-cast surfaces, including not only the sound castings but also those with different degrees of porosity, agreed closely with the properties of the separately cast test bars. The yield strengths of the plate-type specimens generally were slightly higher.

11. Grit-blasting the surfaces of the plate-type specimens had no harmful effect on the tensile properties.

12. Shot-blasting lowered the tensile strength about 9 percent but increased the yield strength slightly.

13. The specimens containing welds had tensile strengths about 4 percent less than the sound specimens without welds.

Aluminum Research Laboratories  
Aluminum Company of America  
New Kensington, Pa., July 3, 1947

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Proc. A.S.T.M., vol. 39, 1939, pp. 711-721.
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TABLE I  
DESCRIPTION OF VARIOUS LOTS OF SAND-CAST SPECIMENS  
OF 355-T6 ALLOY

Lot number	Specimen number	Description
L-2216	4	Cast with dross in massive form in center of reduced section
L-2216	5	Cast with dross in massive form at edge of specimen (dross did not weld in casting)
L-2216	6	Sand hole $\frac{1}{4}$ inch in diameter and $\frac{1}{8}$ inch deep at edge of specimen
L-2216	7	Sand hole $\frac{1}{4}$ inch in diameter and $\frac{1}{8}$ inch deep at center of reduced section
L-2216	8	Cast with ribbon-shaped dross $\frac{3}{4}$ inch long set transversely in middle of specimen
L-2216	9	Cast with ribbon-shaped dross $\frac{3}{4}$ inch long set longitudinally in middle of specimen
L-2216	11	Cast with oxidized aluminum strip $\frac{3}{4}$ inch long set longitudinally in middle of specimen; plane of strip normal to surface
L-2238	6, 7, 8	Sound castings with no intentional defects
L-2246	1, 2, 3, 6, 8, 10	Sound castings with as-cast surface; general fine porosity (probably 1.0 to 1.5 percent; good commercial castings)
L-2246	4, 5, 9, 11, 12	Grit-blasted surfaces (granular steel grit, AFA no. 51; 102 psi pressure; $\frac{3}{8}$ -by 3-inch nozzle 8 to 12 inches from surface)
L-2246	14	Large sand hole at edge of specimen which was repaired by welding
L-2246	15	Large sand hole at edge of specimen
L-2257	2, 3, 4, 9, 13	Shot-blasted surfaces (no. 17 steel shot; $\frac{1}{16}$ inch in diameter, 80 psi pressure; $\frac{3}{8}$ -by 3-inch nozzle 12 to 16 inches from surface)
L-2257	5, 6, 8, 11	Cast with a thin aluminum strip $\frac{3}{4}$ inch long set transversely at middle of specimen
L-2258	15	Sand-blasted surface (AFA no. 40, silica sand; 93 psi pressure)
R-9524	1 to 8	Heavily regassed with 25 grams of $\text{NH}_4\text{Cl}$ before pouring; contained considerable fine porosity; 2.4 percent voids
R-9525	5, 7	Slightly regassed with 4 grams of $\text{NH}_4\text{Cl}$ before pouring; contained some fine porosity; 1.65 percent voids
R-9526	3 to 8	Not regassed; contained very slight porosity; 0.8 percent voids
R-9773	1 to 6	Contained about 0.7 percent voids
R-9774	1 to 6	Contained about 2.4 percent voids
C-175	3, 4	Sound castings containing no intentional defects
C-183	1 to 6	Weld at edge of test section about $1\frac{1}{8}$ inches long, $\frac{3}{4}$ inch wide; heat-treated after welding
C-185	2 to 8	Weld at center of test section about $1\frac{1}{2}$ inches in diameter; heat-treated after welding
C-1205	H	Sound casting with no intentional defects (used only in tension test)

TABLE II  
RESULTS OF TENSILE TESTS OF SEPARATELY CAST TEST BARS REPRESENTING  
VARIOUS LOTS OF 355-T6 ALLOY SAND-CAST FATIGUE SPECIMENS

Lot number	Tensile strength (psi)	Yield strength (offset, 0.2 percent) (psi)	Elongation in 2 in. (percent)
Typical values <sup>1</sup>	35,000	25,000	2.5
Specified minimum values <sup>2</sup>	32,000	-----	2
L-2216	37,000	27,300	3.5
L-2238	38,300	33,600	4.1
L-2246	34,900	29,300	3.5
L-2257	36,220	28,050	2.3
L-2258	33,000	28,200	1.3
R-9524	33,400	25,800	2.4
R-9525	34,125	25,775	2.6
R-9526	34,500	26,625	2.4
R-9773 and R-9774		Data not available	
C-175, C-183, and C-185	36,250	30,300	2.1
C-1205	36,200	29,300	3.0

<sup>1</sup>Reference 2.

<sup>2</sup>A.S.T.M. specification B26-46T, alloy SC21; federal specification QQ-A-601, class 10HT1; Army-Navy aeronautical specification AN-A-40.

TABLE III

## RESULTS OF FATIGUE TESTS OF SOUND SPECIMENS WITHOUT INTENTIONAL DEFECTS

Specimen number (1)	Surface finish	Stress range (psi) (2)	Cycles	Location of failure
L-2246-1	As-cast	0 to 14,860	142,100	Near edge of fillet
L-2246-2	As-cast	0 to 9,600	1,423,900	Edge of fillet
L-2246-3	As-cast	0 to 7,400	9,550,900	Edge of fillet
L-2246-6	As-cast	0 to 12,310	532,700	Center of reduced section
L-2246-8	As-cast	0 to 6,320	99,779,800	No failure
L-2246-10	As-cast	0 to 8,580	1,959,000	Near center of reduced section
L-2238-6	As-cast	0 to 9,050	3,527,100	Edge of fillet
L-2238-7	As-cast	0 to 12,130	592,800	Edge of fillet
L-2238-8	As-cast	0 to 14,910	418,600	Edge of fillet
C-175-3	As-cast	0 to 10,400	817,000	Center of reduced section
C-175-4	As-cast	0 to 7,970	2,922,800	Near center of reduced section

<sup>1</sup>Reduced section  $7\frac{1}{2}$  inches wide.

<sup>2</sup>From zero to a maximum value in tension.

TABLE IV  
RESULTS OF FATIGUE TESTS OF SPECIMENS WITH DIFFERENT SURFACE FINISHES

Specimen number (1)	Surface finish	Stress range (psi) (2)	Cycles	Location of failure
L-2246-4	Grit-blasted	0 to 8,360	25,105,600	No failure
L-2246-5	Grit-blasted	0 to 14,050	197,600	Near edge of fillet
L-2246-9	Grit-blasted	0 to 10,610	1,223,700	Near center of reduced section
L-2246-11	Grit-blasted	0 to 9,390	18,080,600	Near center of reduced section
L-2246-12	Grit-blasted	0 to 7,310	25,170,200	No failure
L-2257-2	Shot-blasted	0 to 14,980	68,700	Edge of fillet
L-2257-3	Shot-blasted	0 to 12,480	262,600	Edge of fillet
L-2257-4	Shot-blasted	0 to 8,460	25,291,700	No failure
L-2257-9	Shot-blasted	0 to 9,950	1,041,200	Near center of reduced section
L-2257-13	Shot-blasted	0 to 9,220	25,570,500	No failure
L-2258-15	Sand-blasted	0 to 10,050	1,821,000	Edge of fillet

<sup>1</sup>Reduced section  $7\frac{1}{2}$  inches wide.

<sup>2</sup>From zero to a maximum value in tension.

TABLE V  
RESULTS OF FATIGUE TESTS OF SPECIMENS WITH DIFFERENT SURFACE  
FINISHES AND DIFFERENT AMOUNTS OF POROSITY

Specimen number	Surface finish	Voids (percent)	Stress range (psi) (b)	Cycles	Location of failure
R-9526-3	As-cast	0.8	0 to 12,400	295,700	Near center of reduced section
R-9526-4	As-cast	.8	0 to 7,460	2,143,100	Center of reduced section
R-9526-5	As-cast	.8	0 to 9,880	1,575,000	Edge of fillet
R-9526-6	As-cast	.8	0 to 8,950	1,184,000	Near center of reduced section
R-9526-7	As-cast	.8	0 to 5,930	104,302,300	No failure
R-9526-8	As-cast	.8	0 to 14,970	218,500	Near center of reduced section
R-9524-1	As-cast	2.4	0 to 15,000	195,700	Edge of fillet
R-9524-2	As-cast	2.4	0 to 12,460	328,800	Near center of reduced section
R-9524-3	As-cast	2.4	0 to 10,000	536,400	Center of reduced section
R-9524-4	As-cast	2.4	0 to 7,480	5,124,500	Near center of reduced section
R-9524-5	As-cast	2.4	0 to 8,930	1,715,000	Center of reduced section
R-9524-6	As-cast	2.4	0 to 6,020	56,413,700	No failure
R-9524-7	As-cast	2.4	0 to 10,000	766,000	Near center of reduced section
R-9524-8	As-cast	2.4	0 to 6,440	8,526,300	Edge of fillet
R-9773-1	Machined	.7	0 to 14,870	58,100	Edge of fillet
<sup>a</sup> R-9773-2	Machined	.7	0 to 9,520	1,813,700	Edge of fillet
R-9773-3	Machined	.7	0 to 8,000	6,133,400	Edge of fillet
<sup>a</sup> R-9773-4	Machined	.7	0 to 12,560	619,600	Near center of reduced section
<sup>a</sup> R-9773-5	Machined	.7	0 to 9,020	4,285,100	Edge of fillet
R-9773-6	Machined	.7	0 to 7,930	1,038,200	Near center of reduced section
<sup>a</sup> R-9774-1	Machined	2.4	0 to 8,880	601,400	Edge of fillet
<sup>a</sup> R-9774-2	Machined	2.4	0 to 6,460	2,055,400	Edge of fillet
R-9774-3	Machined	2.4	0 to 14,660	193,600	Edge of fillet
<sup>a</sup> R-9774-4	Machined	2.4	0 to 6,960	9,505,200	Edge of fillet
R-9774-5	Machined	2.4	0 to 12,470	285,900	Edge of fillet
R-9774-6	Machined	2.4	0 to 6,030	19,245,500	Center of reduced section

<sup>a</sup>Reduced section  $5\frac{1}{2}$  inches wide; in all other tests,  $7\frac{1}{2}$  inches wide.

<sup>b</sup>From zero to a maximum value in tension.

TABLE VI

## RESULTS OF FATIGUE TESTS OF SPECIMENS CONTAINING INTENTIONAL DEFECTS

Specimen number (1)	Description of intentional defect	Stress range (psi) (2)	Cycles	Location of failure
L-2216-4	Dross in center of specimen	0 to 8,990	1,366,600	Edge of fillet
L-2216-5	Dross at edge of specimen	0 to 8,900	466,200	Through dross
L-2216-6	Sand hole at edge of specimen	0 to 9,060	241,400	Through sand hole
L-2216-7	Sand hole at center of specimen	0 to 9,040	1,401,100	Edge of fillet
L-2216-8	Transverse dross film at center	0 to 9,110	302,300	Through dross film
L-2216-9	Longitudinal dross film at center	0 to 8,900	3,710,700	Edge of fillet
L-2216-11	Longitudinal oxidized aluminum strip at center	0 to 8,940	5,658,700	Edge of fillet
L-2246-14	Sand hole at edge repaired by welding	0 to 9,310	1,687,800	Through weld
L-2246-15	Sand hole at edge	0 to 8,970	610,600	Through sand hole
L-2257-5	Transverse aluminum strip at center	0 to 14,930	24,500	Through aluminum strip
L-2257-6	Transverse aluminum strip at center	0 to 12,430	177,000	Through aluminum strip
L-2257-8	Transverse aluminum strip at center	0 to 10,000	838,800	Through aluminum strip
L-2257-11	Transverse aluminum strip at center	0 to 8,210	3,994,200	Through aluminum strip
C-183-1	Weld $1\frac{1}{8}$ inches long by $\frac{3}{4}$ inch wide at edge; good weld	0 to 15,230	176,400	Near center of reduced section
C-183-2	Weld $1\frac{1}{8}$ inches long by $\frac{3}{4}$ inch wide at edge; good weld	0 to 9,830	1,029,400	Through weld
C-183-3	Weld $1\frac{1}{8}$ inches long by $\frac{3}{4}$ inch wide at edge; good weld	0 to 7,990	1,065,400	Through weld
C-183-4	Weld $1\frac{1}{8}$ inches long by $\frac{3}{4}$ inch wide at edge; fair weld	0 to 7,160	98,847,500	Edge of weld
C-183-5	Weld $1\frac{1}{8}$ inches long by $\frac{3}{4}$ inch wide at edge; good weld	0 to 7,510	2,615,200	Edge of weld
C-183-6	Weld $1\frac{1}{8}$ inches long by $\frac{3}{4}$ inch wide at edge; good weld	0 to 7,970	19,441,500	Edge of fillet
C-185-2	Weld $1\frac{1}{2}$ inches in diameter at center; good weld	0 to 15,020	178,600	Through weld
C-185-3	Weld $1\frac{1}{2}$ inches in diameter at center; fair weld	0 to 9,740	1,054,500	Edge of weld
C-185-4	Weld $1\frac{1}{2}$ inches in diameter at center; good weld	0 to 7,900	790,300	Through weld
C-185-5	Weld $1\frac{1}{2}$ inches in diameter at center; good weld	0 to 6,910	661,500	Near center of reduced section
C-185-6	Weld $1\frac{1}{2}$ inches in diameter at center; good weld	0 to 5,950	44,568,700	No failure
C-185-7	Weld $1\frac{1}{2}$ inches in diameter at center; fair weld	0 to 7,450	56,167,400	No failure
C-185-8	Weld $1\frac{1}{2}$ inches in diameter at center; good weld	0 to 7,940	1,036,200	Edge of weld

<sup>1</sup>Surfaces as-cast. Reduced section  $1\frac{1}{2}$  inches wide.<sup>2</sup>From zero to a maximum value in tension.

TABLE VII  
RESULTS OF TENSILE TESTS OF 355-T6 ALLOY SAND-CAST, PLATE-TYPE SPECIMENS  
PREVIOUSLY SUBJECTED TO FATIGUE STRESSING

Lot number	Specimen number	Description	Prior fatigue stressing		Tensile properties				
			Stress range (psi) (a)	Cycles	Tensile strength, (psi)	Yield strength (offset, 0.2-percent) (psi)	Elongation (percent) in -		
							2 in.	4 in.	6 in.
Specimen not subjected to fatigue stresses									
C-1205	H	Sound casting; as-cast surfaces	None	-----	35,200	29,900	---	---	---
Specimens previously subjected to fatigue stresses									
L-2246	8	Sound casting; as-cast surfaces	0 to 6320	99,779,800	35,100	30,100	3.0	2.1	1.7
L-2246	4	Grit-blasted surfaces	0 to 8360	25,105,600	34,200	27,500	3.3	2.3	1.9
	12		0 to 7310	25,170,200	36,200	29,500	3.2	2.4	1.7
					Av. 35,200	28,500	3.3	2.4	1.8
L-2257	4	Shot-blasted surfaces	0 to 8460	25,291,700	<sup>b</sup> 27,400	(c)	<sup>b</sup> 1.7	<sup>b</sup> 1.0	<sup>b</sup> .7
	13		0 to 9220	25,370,500	33,000	29,000	2.2	1.6	1.2
					Av. 33,000	29,000	2.2	1.6	1.2
R-9526	7	0.8-percent voids; as-cast surfaces	0 to 5930	104,302,300	34,600	31,600	2.7	1.6	1.4
R-9525	5	1.65-percent voids; as-cast	0 to 5050	24,778,800	32,900	30,100	2.0	1.4	1.0
	7	surfaces	0 to 5880	40,254,700	<sup>b</sup> 23,600	(c)	<sup>b</sup> 1.7	<sup>b</sup> .9	<sup>b</sup> .6
					Av. 32,900	30,100	2.0	1.4	1.0
R-9524	6	2.4-percent voids; as-cast surfaces	0 to 6020	56,413,700	<sup>d</sup> 30,700	28,400	<sup>d</sup> 2.5	<sup>d</sup> 1.4	<sup>d</sup> 1.0
Q-185	6	Weld at center; as-cast	0 to 5950	44,568,700	33,000	32,700	1.7	1.3	.8
	7	surfaces	0 to 7450	56,167,400	34,000	33,700	2.0	1.3	.8
					Av. 33,500	33,200	1.9	1.3	.8

<sup>a</sup>From zero to a maximum value in tension.

<sup>b</sup>Metal defect in specimen; omitted in average.

<sup>c</sup>Specimen failed before 0.2-percent offset was obtained.

<sup>d</sup>Failed through defect.

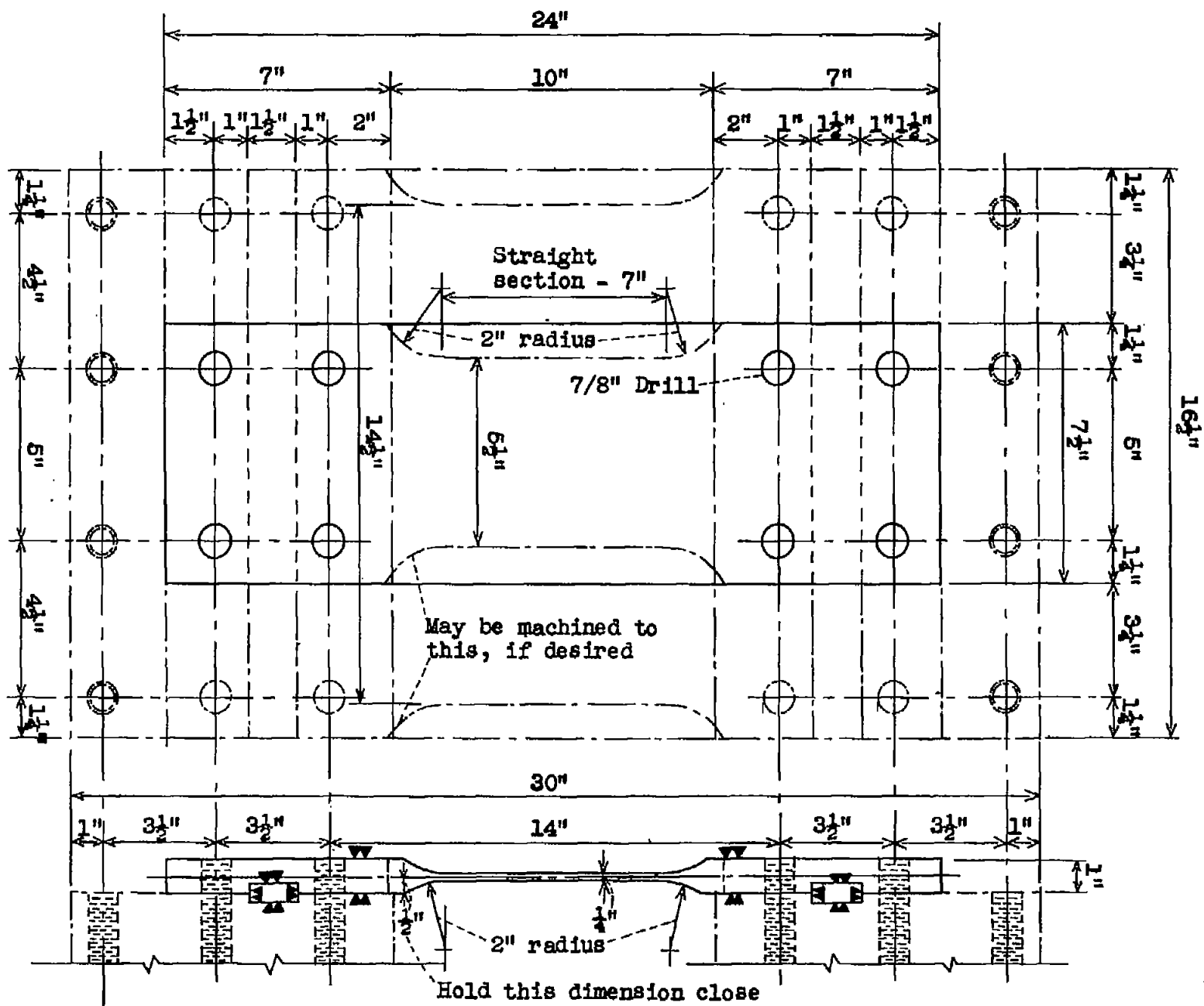


Figure 1.- Specimen for structural fatigue testing machine.

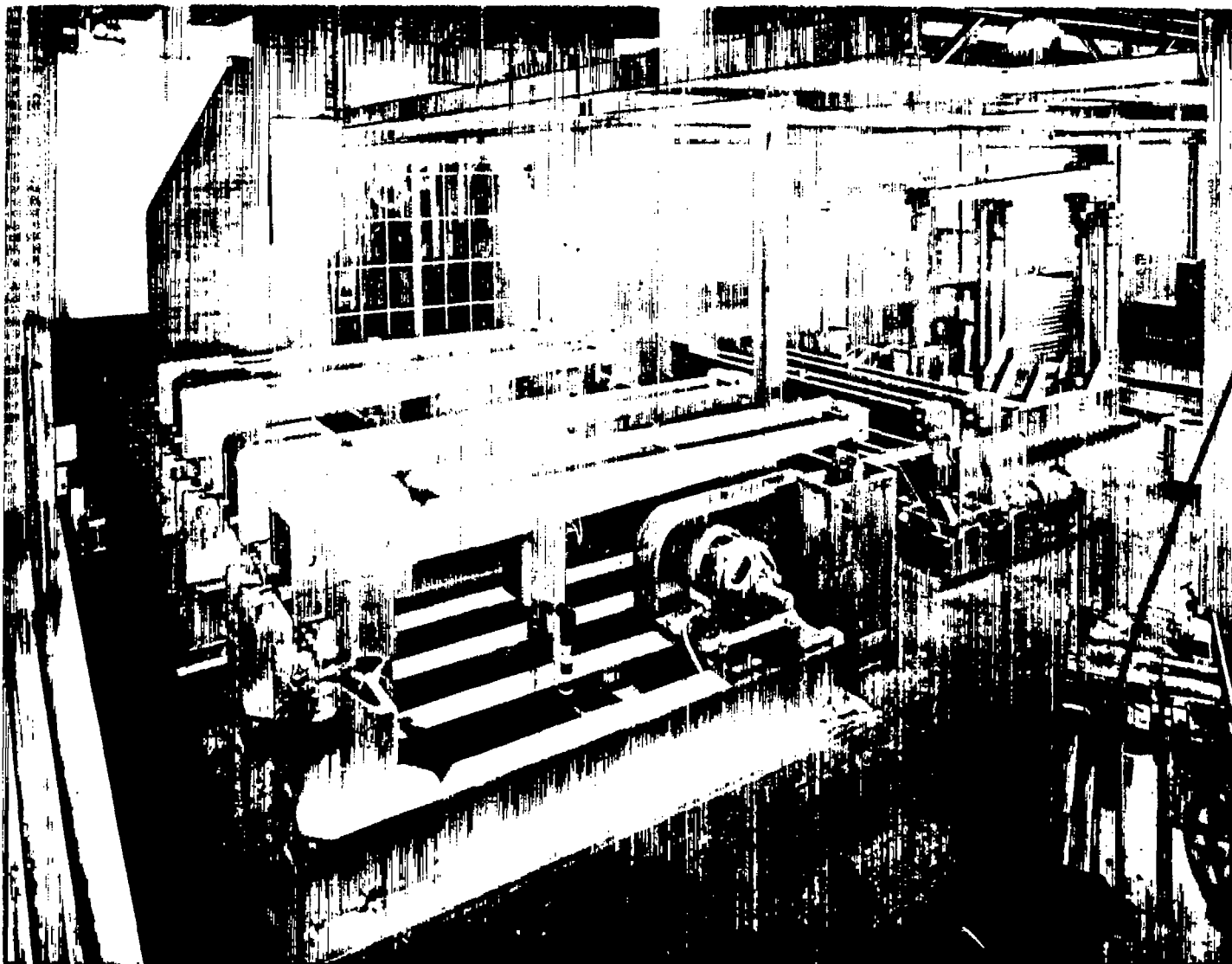


Figure 2.- General view of fatigue machines for testing structural units.



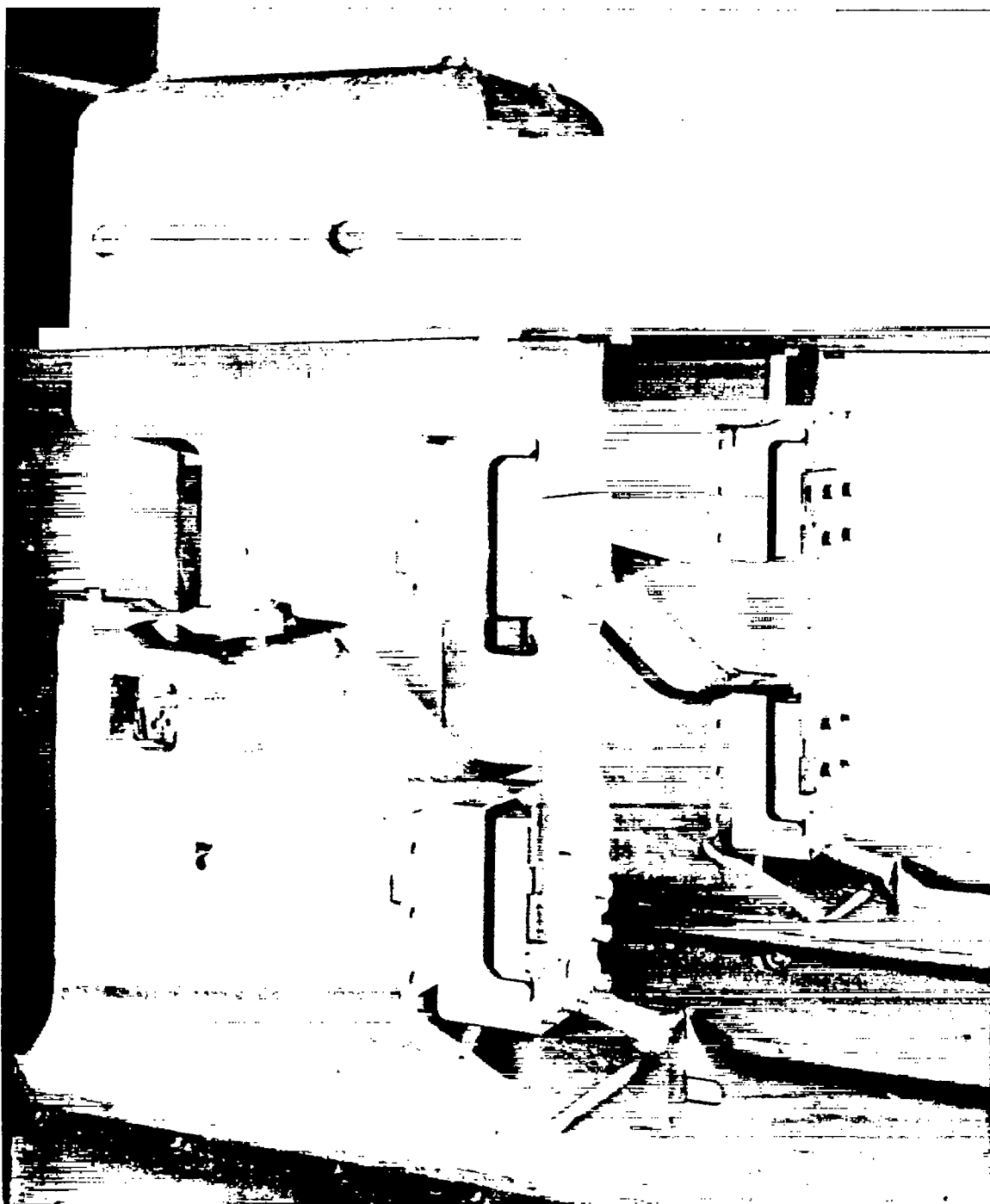
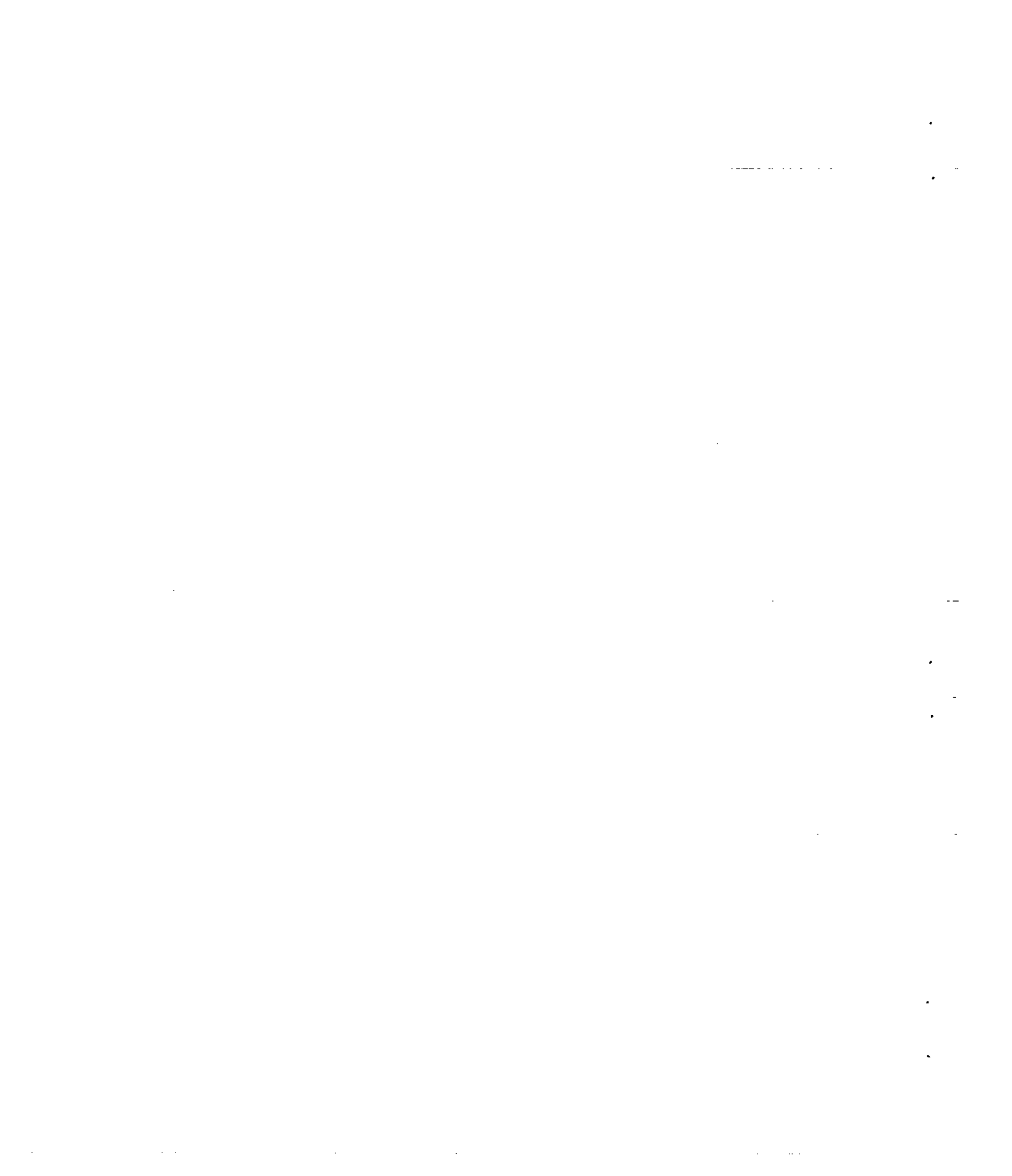


Figure 3.- Fatigue tests of two sand-cast, plate-type specimens showing adapters with plate fulcrums used to minimize bending stresses.



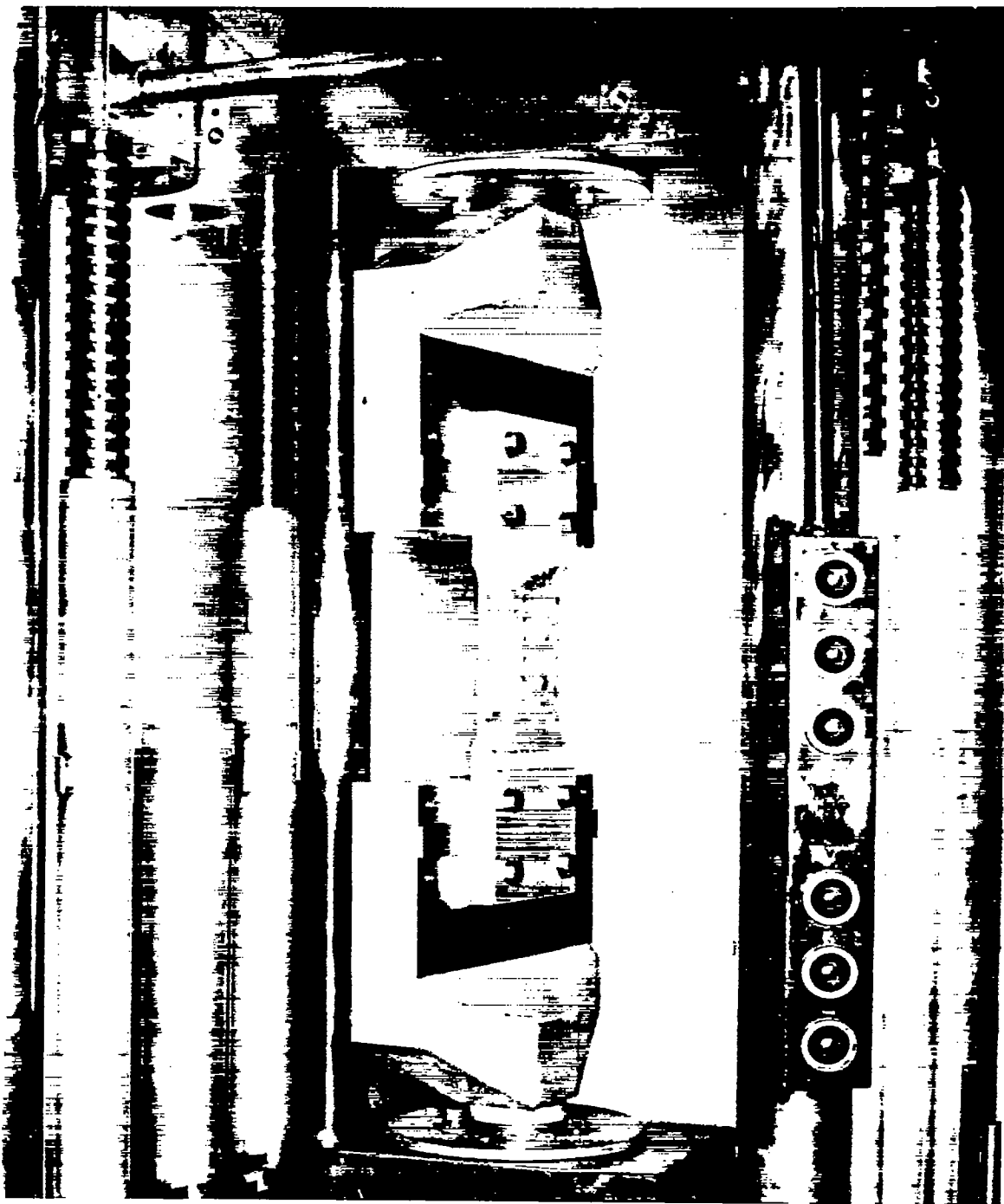


Figure 4.- Tensile test of sand-cast, plate-type specimen.



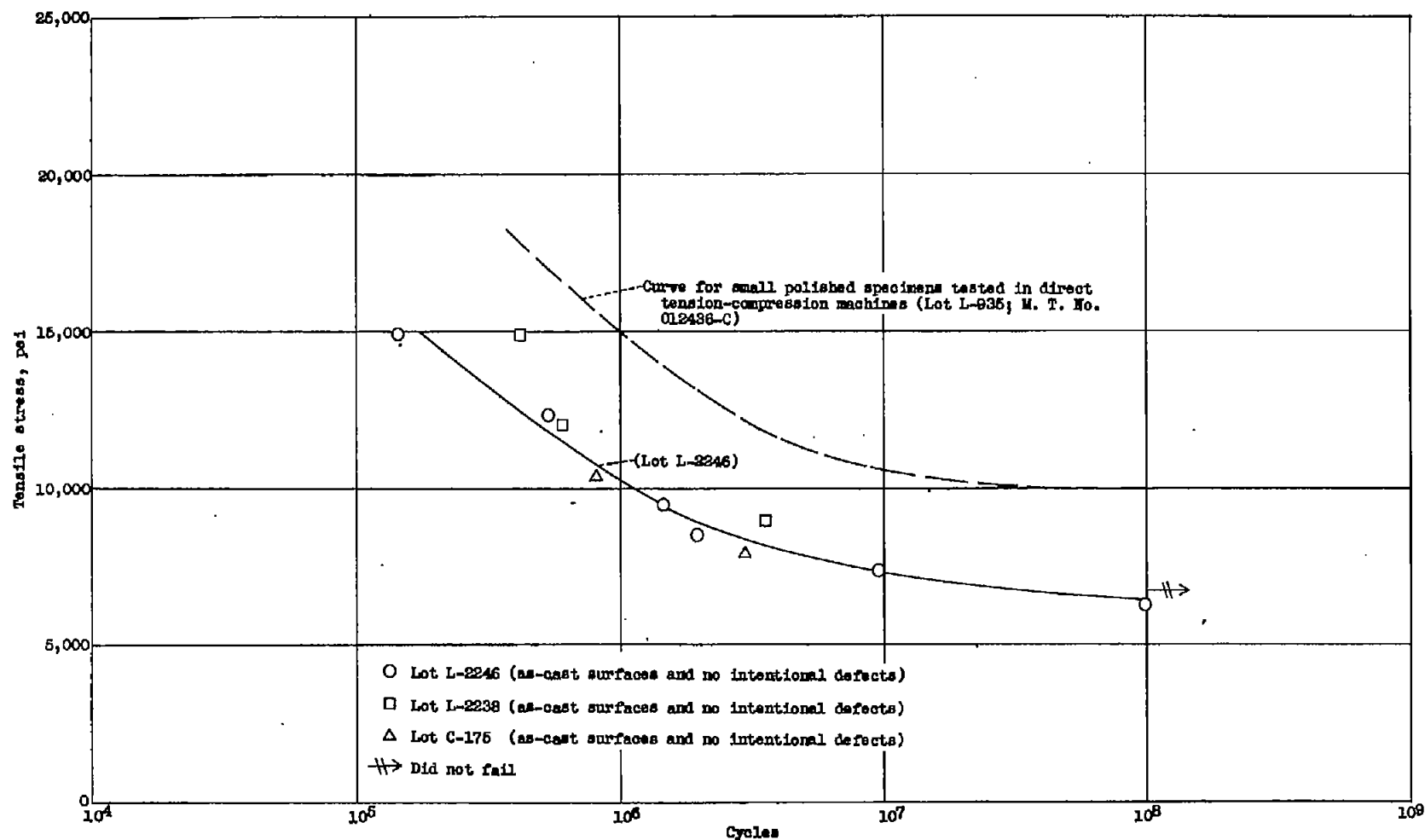


Figure 5(a).- Direct-stress fatigue curve for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

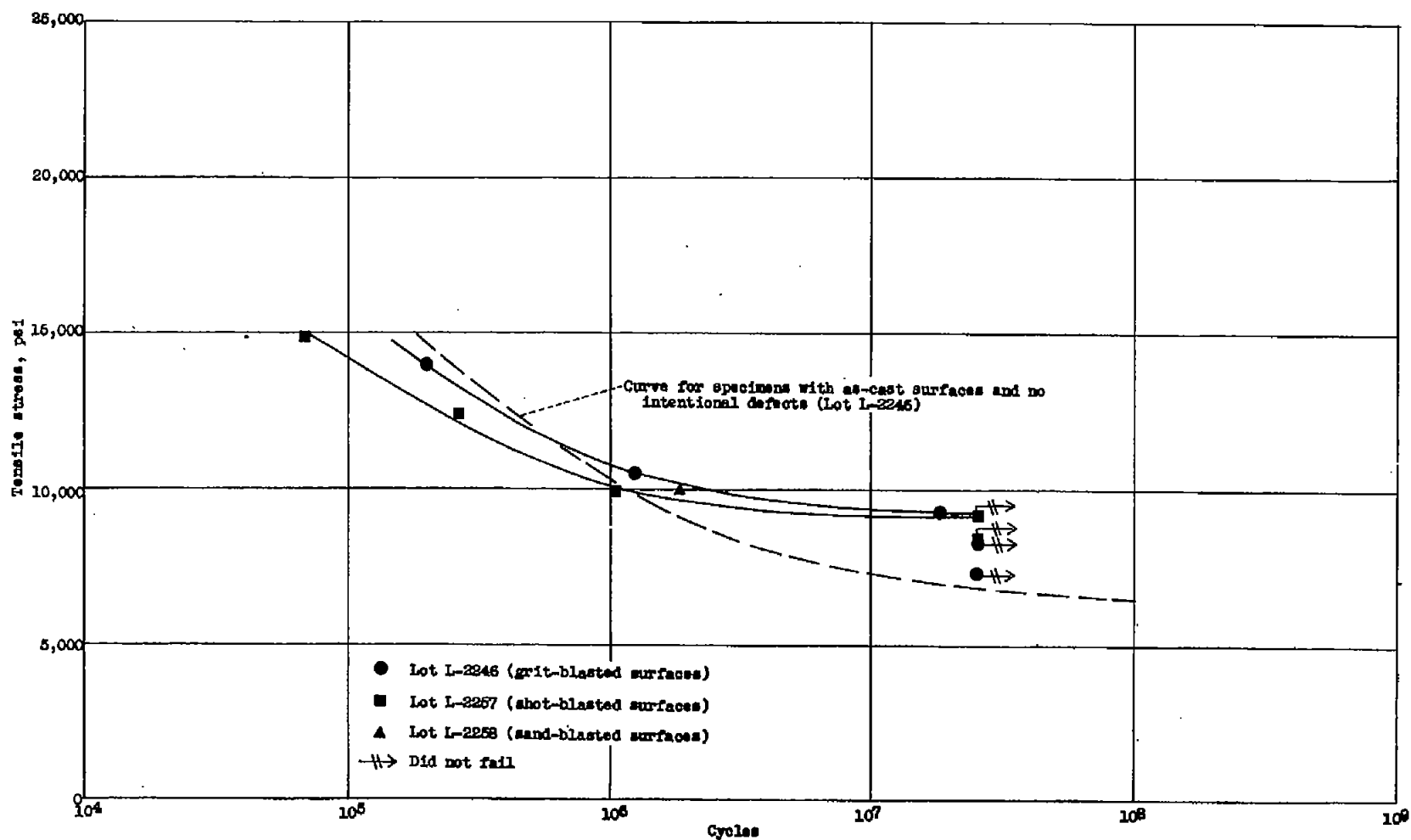


Figure 5(b).- Direct-stress fatigue curves for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

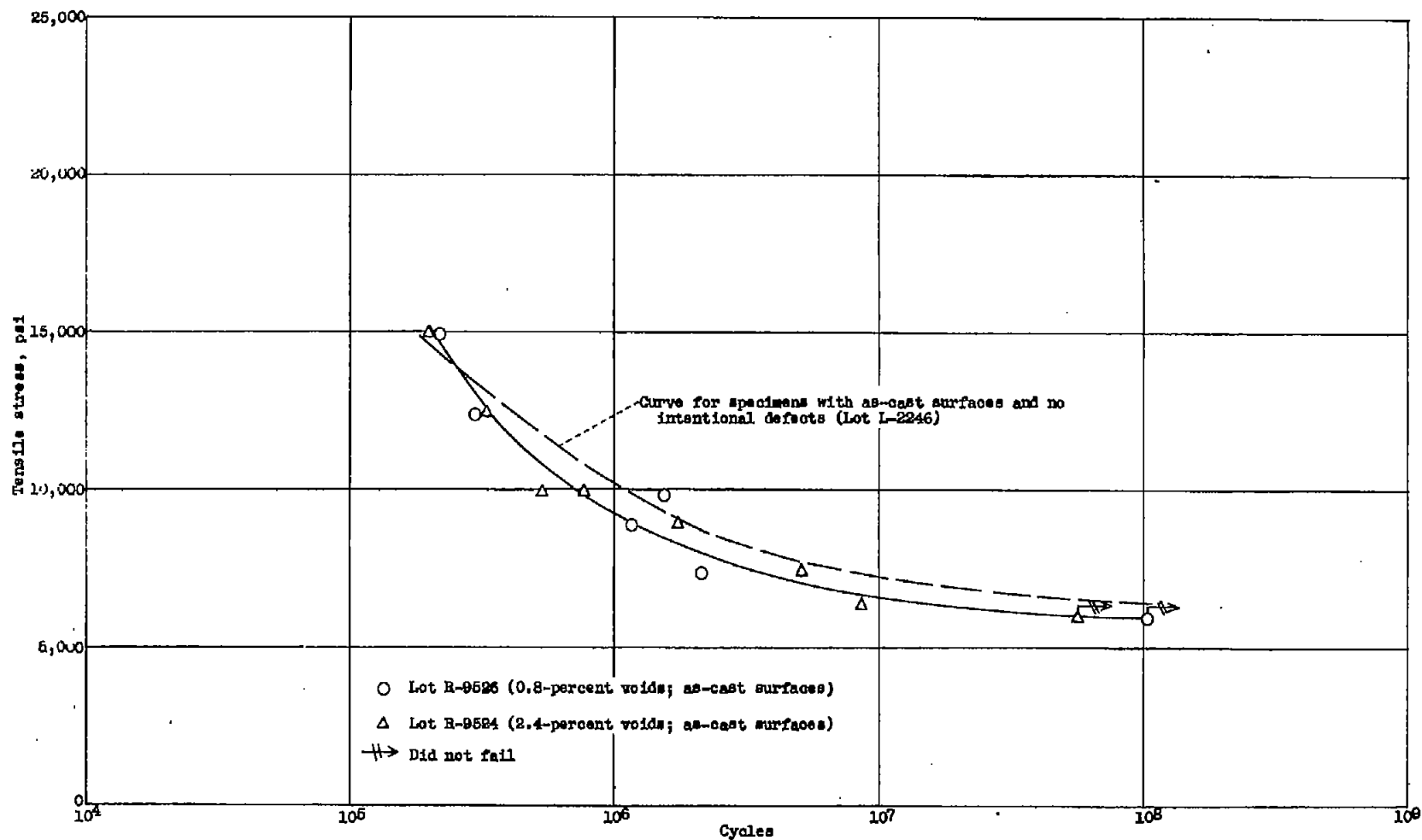


Figure 5(c).- Direct-stress fatigue curves for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

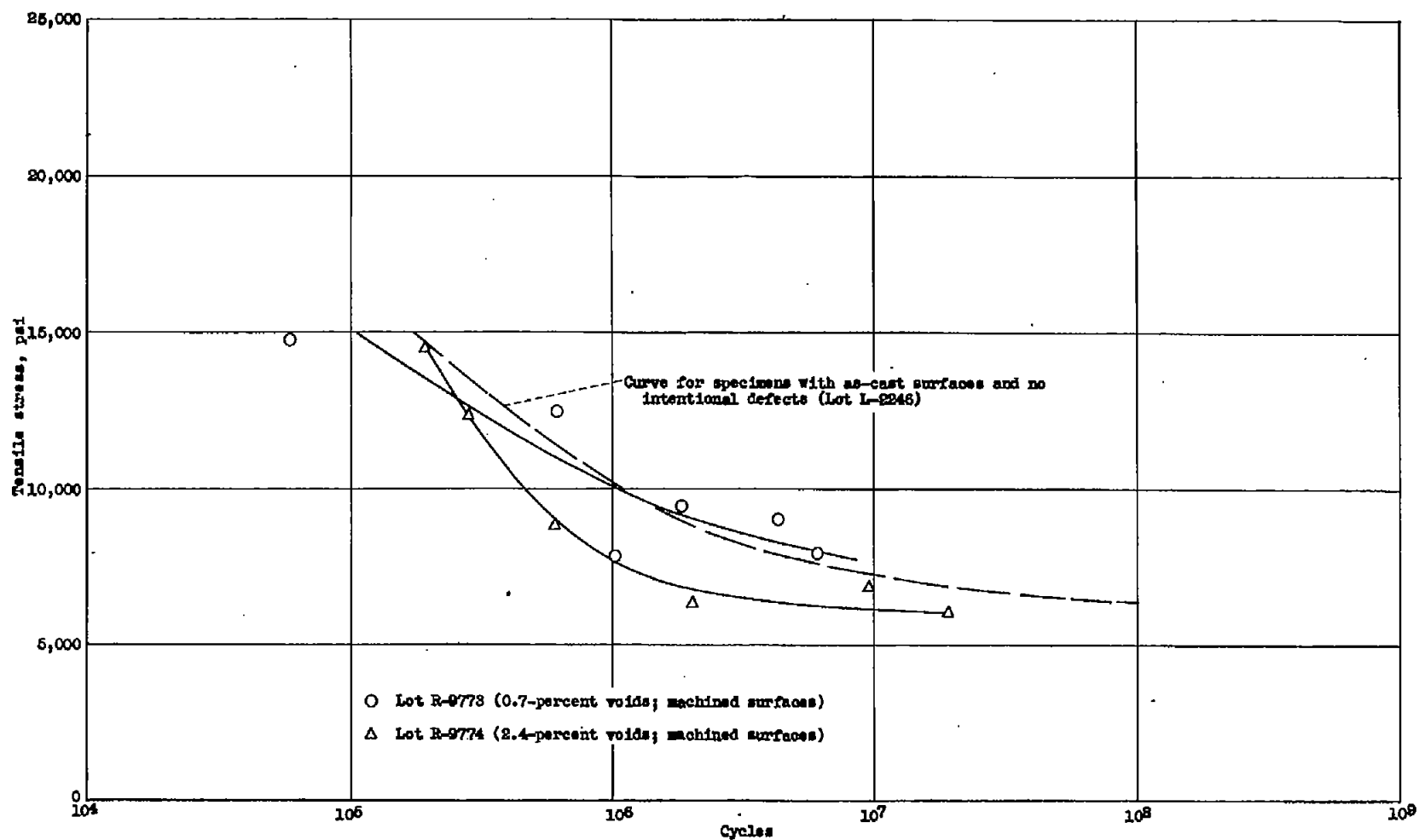


Figure 5(d).- Direct-stress fatigue curves for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

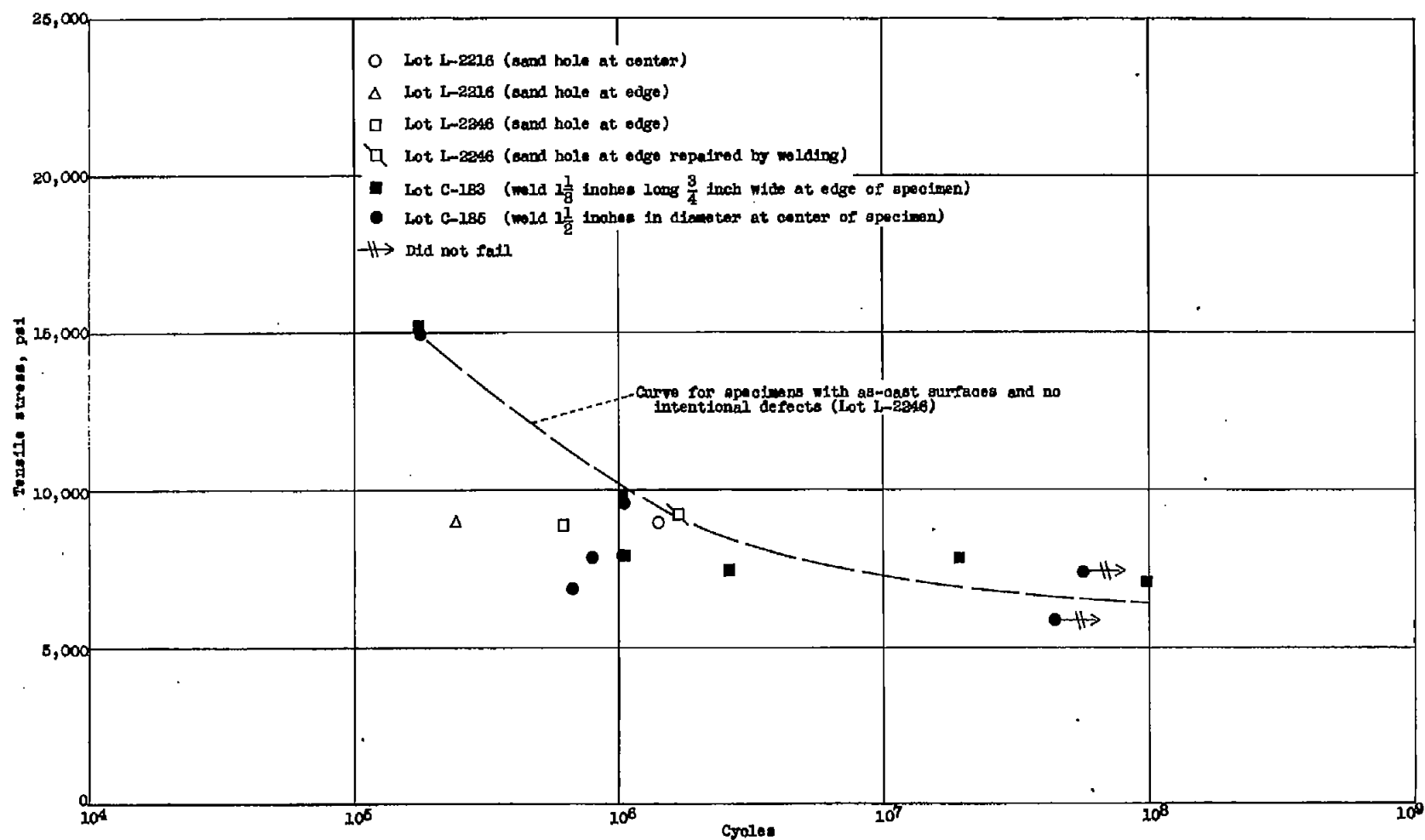


Figure 5(e).- Direct-stress fatigue curve for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

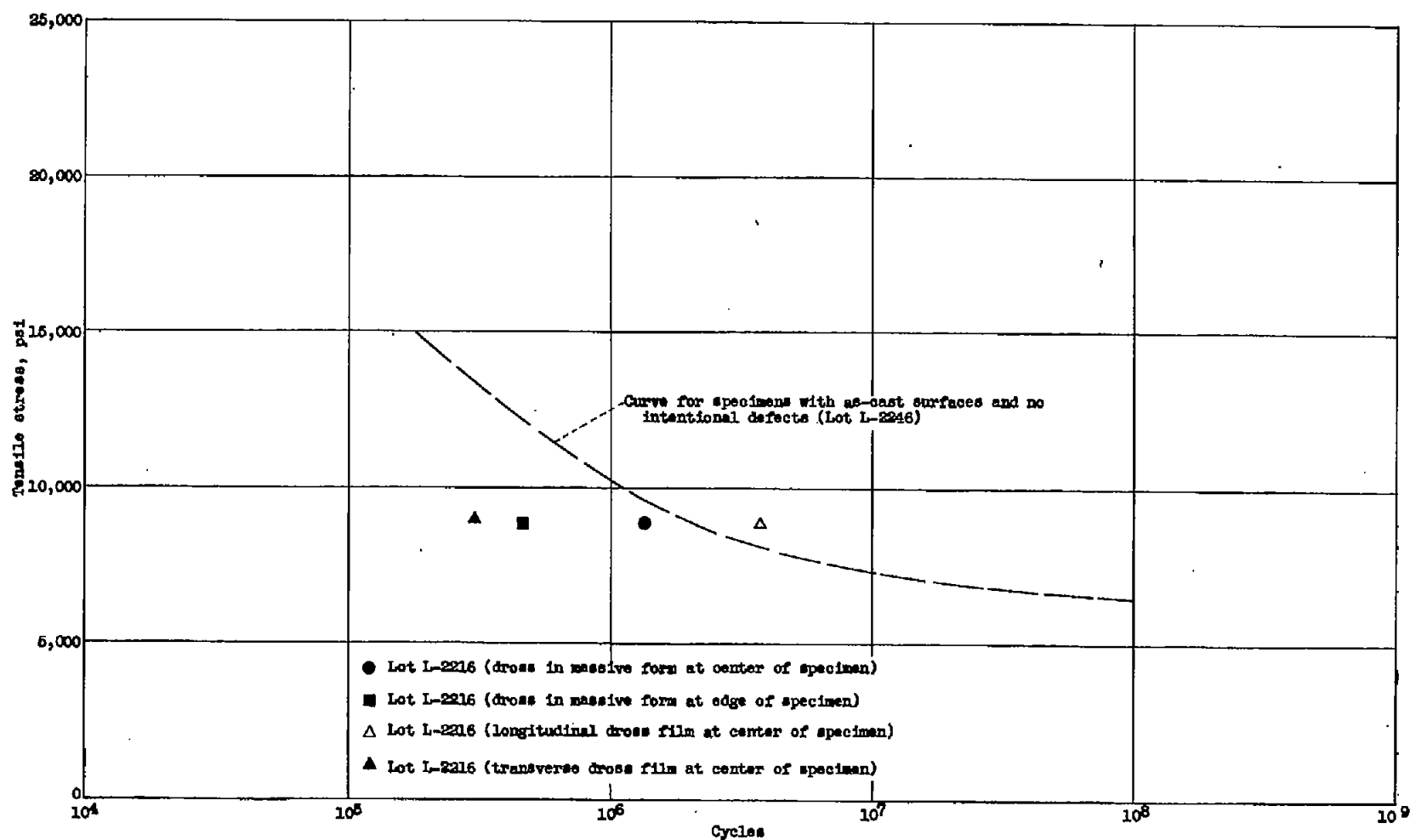


Figure 5(f).-- Direct-stress fatigue curve for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

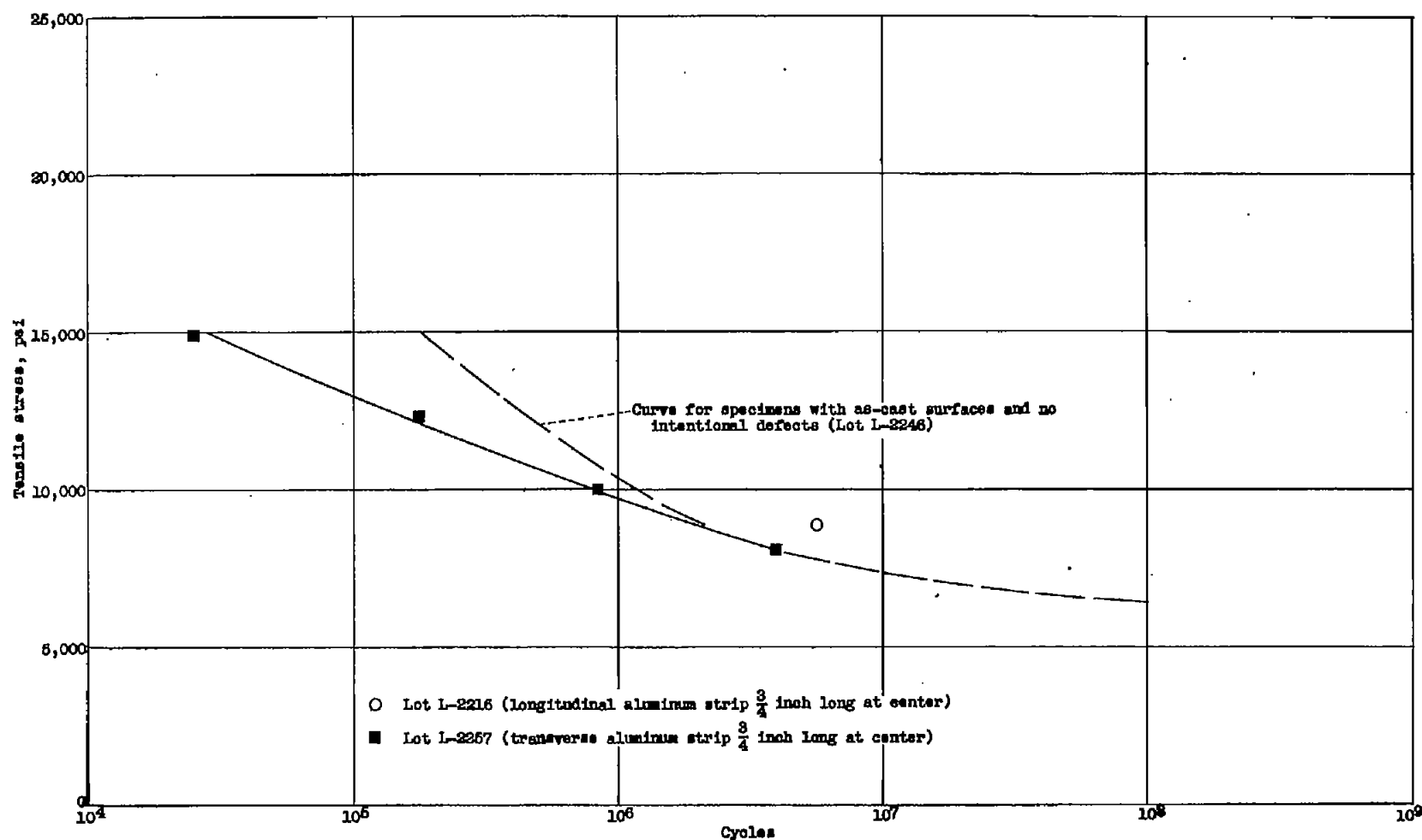


Figure 5(g).- Direct-stress fatigue curves for 355-T6 sand-cast specimens. Ratio of minimum stress to maximum stress equals zero.

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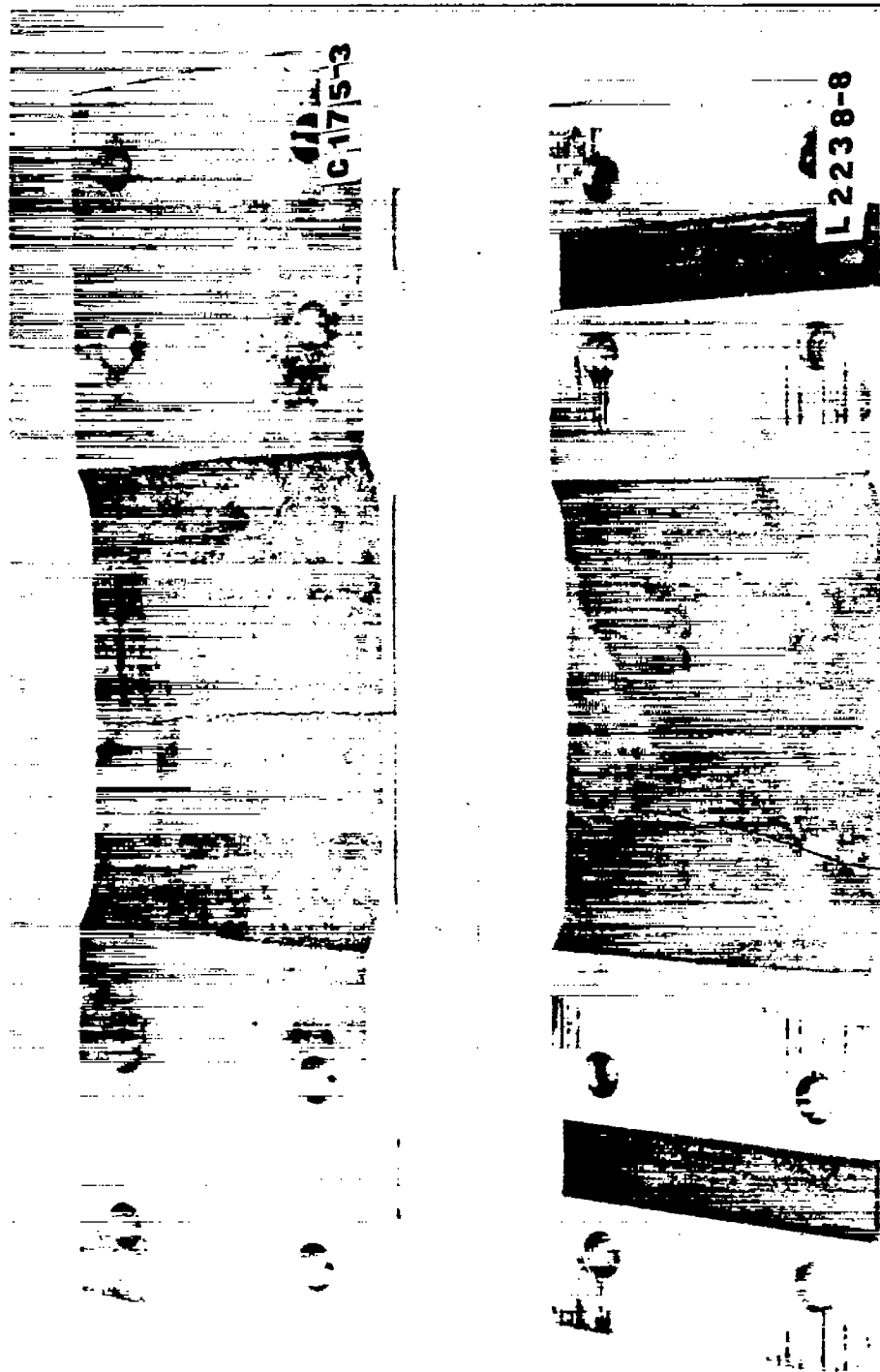


Figure 6.- Fatigue failures of two sound specimens without intentional defects.



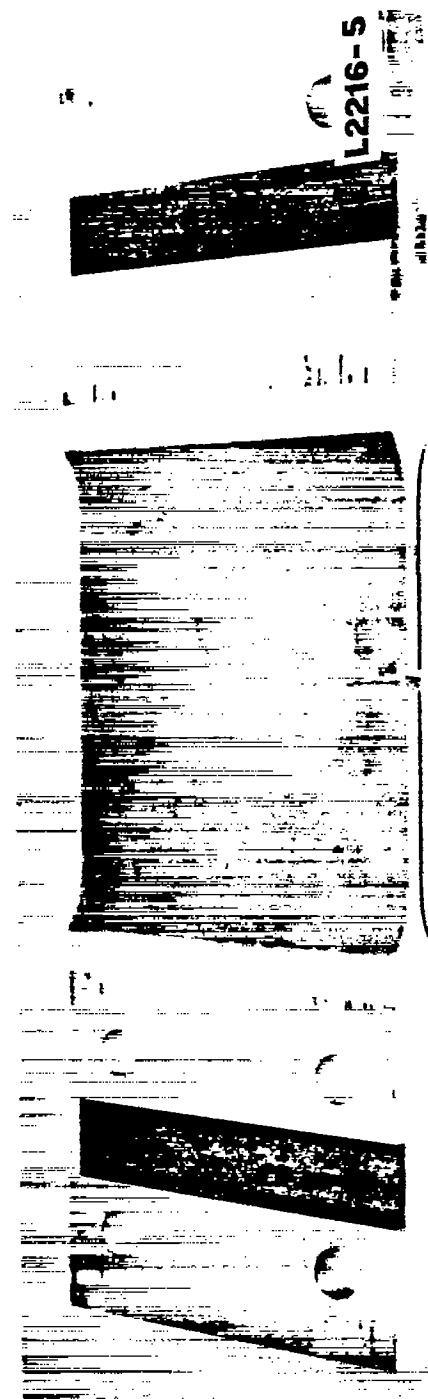


Figure 7.- Fatigue failure of specimen with sand hole at edge.





Figure 8.- Fatigue failure of welded specimen at edge of weld.





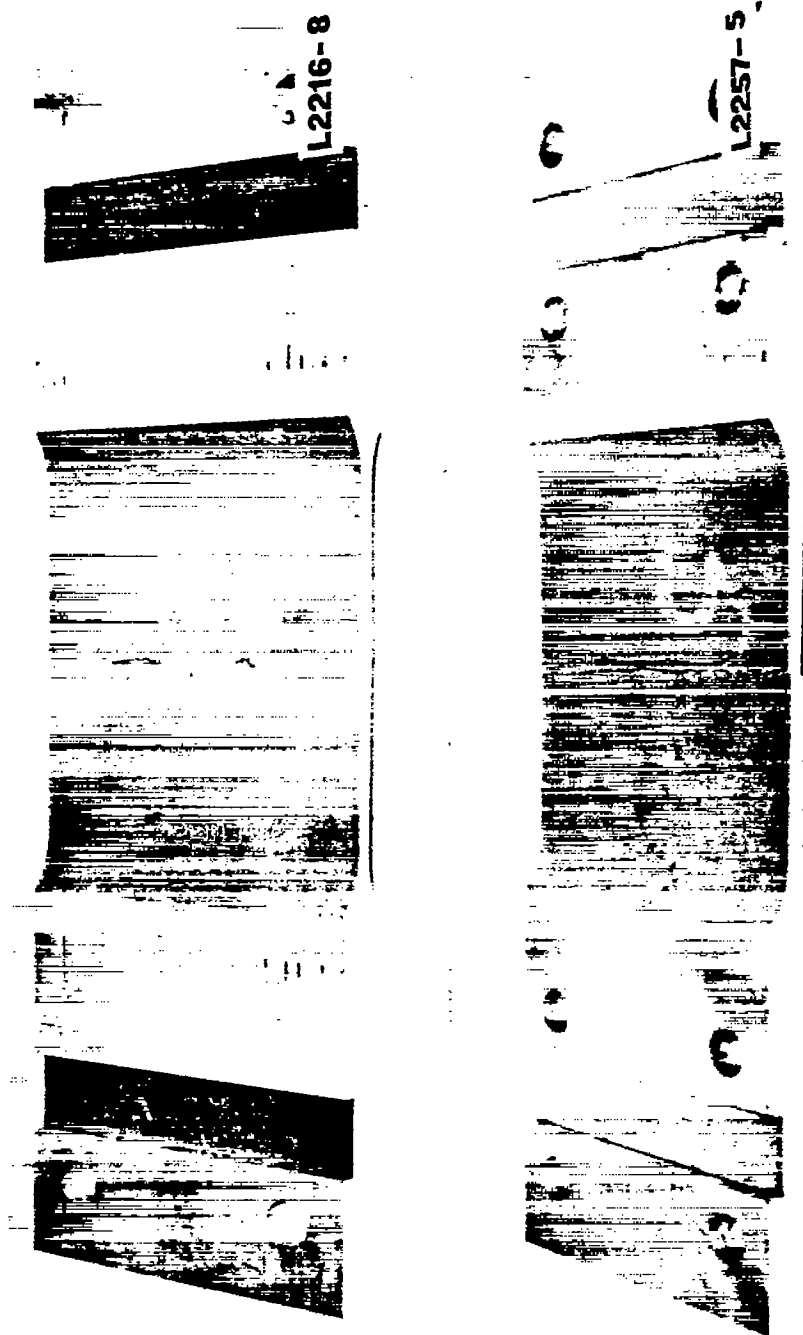
Figure 9.- Fatigue failure of welded specimen between weld and edge of reduced section. Note transverse crack in weld.





Figure 10.- Fatigue failure of welded specimen near end of reduced section.





(a) Defect: ribbon-shaped cross, transverse.

(b) Defect: aluminum strip cast in center, transverse.

Figure 11.- Fatigue failures of specimens with intentional defects



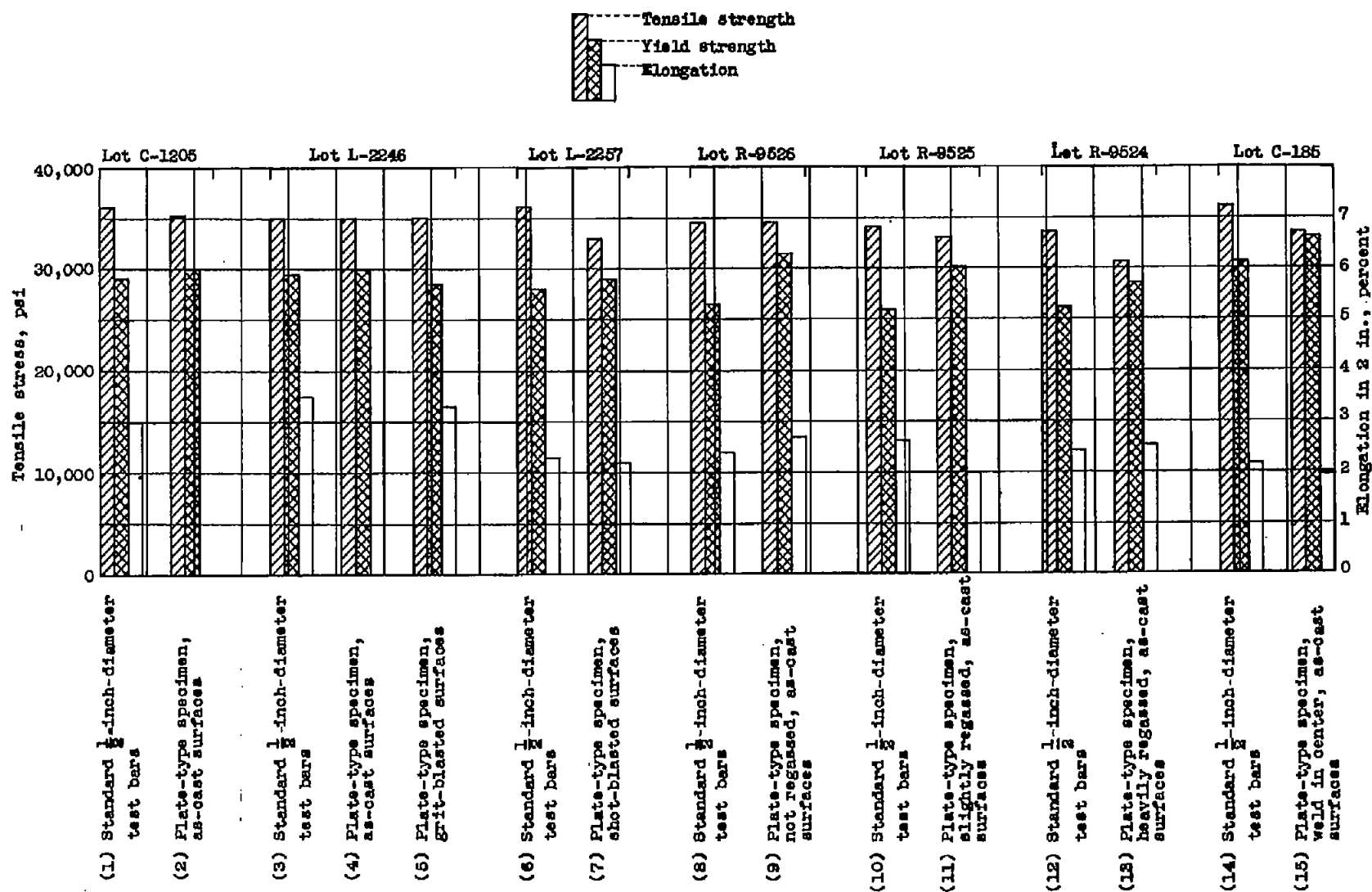


Figure 12.- Results of tensile tests of test bars and plate-type specimens of 355-T6 alloy. Specimens (4), (5), (7), (9), (11), (13), and (15) previously subjected to a fatigue test of at least 25,000,000 cycles. Specimen (13), tensile strength low because specimen failed through defect.



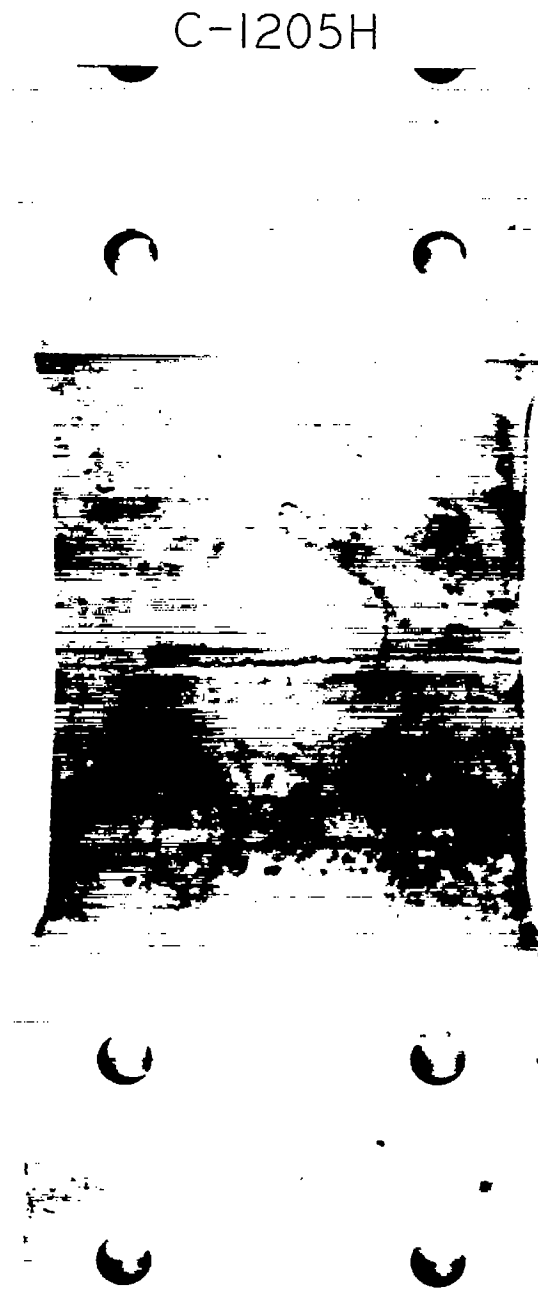


Figure 13.- Tensile failure of specimen not previously subjected to fatigue stressing.



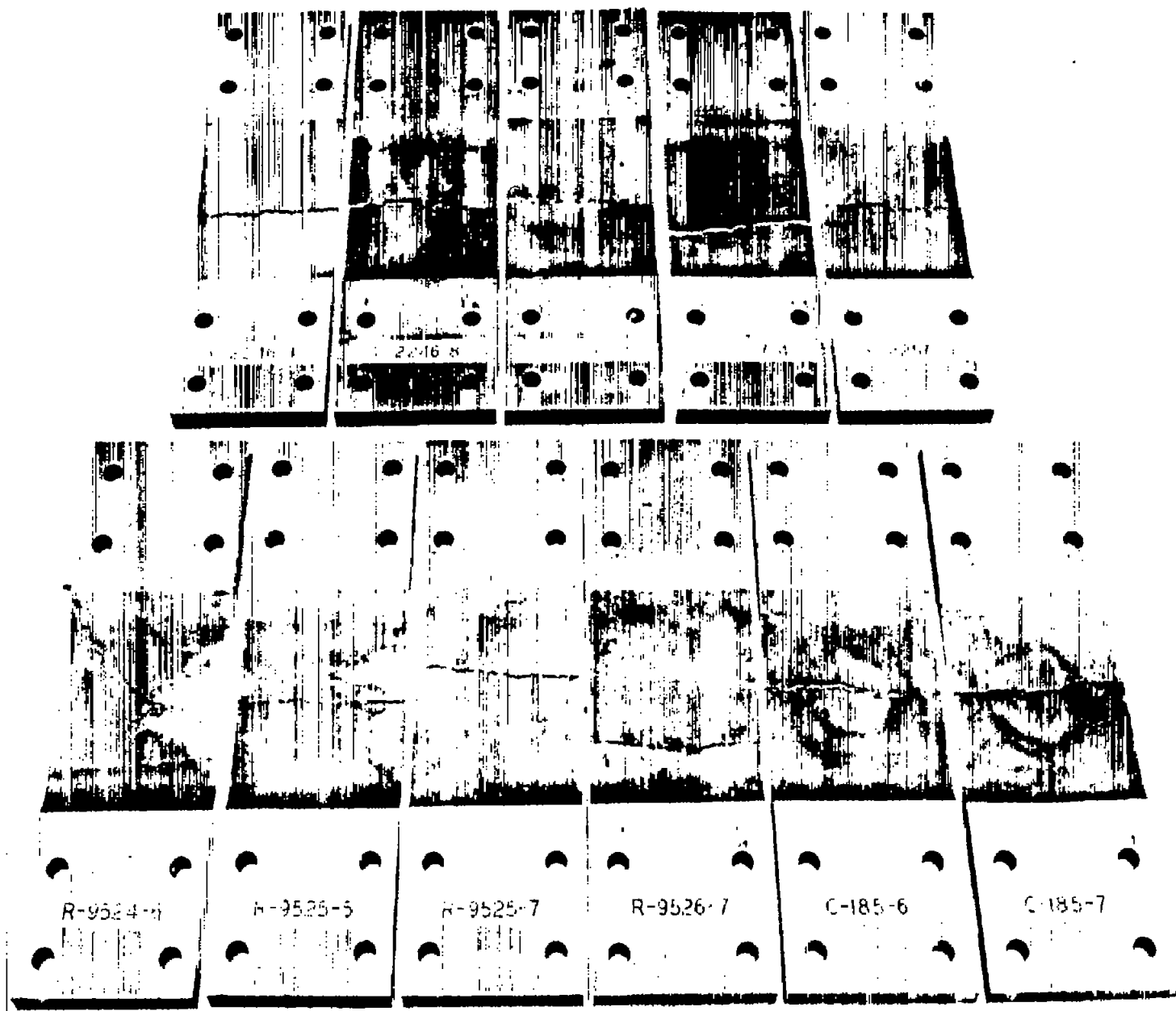


Figure 14.- Tensile failures of specimens previously subjected to fatigue stressing.